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HEAT EXCHANGERS FOR LUMBER DRY KILNS

Division of Land and Economic Resources
Office of Natural Resources and Economic Development
Tennessee Valley Authority
Norris, Tennessee 37828

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Division of Land and Economic Resources
Office of Natural Resources and Economic Development
Tennessee Valley Authority
Knoxville, Tennessee 37902

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HEAT EXCHANGERS FOR LUMBER DRY KILNS

ABSTRACT

An air-to-air, flat-plate heat exchanger was used to recover exhausted heat from an 80 MBF capacity commercial dry kiln. Heat exchanger efficiency averaged 46 percent and ranged from 20 to 90 percent on the 10 charges studied. Energy consumption of the dry kiln was reduced by 18 percent. Natural gas savings at a cost of $5.65 per MCF were $1.76 per MBF for yellow-poplar and $4.70 for red oak. Estimated payback periods are: 1.05 years for oak and 1.15 years for yellow-poplar.

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INTRODUCTION

Energy is one of the primary components in the cost of producing lumber, and it is a part of every process from the chain saw in the woods to the transportation of a final product. About 70 percent of the total energy used to process wood into finished products is concentrated in lumber drying. The naturally occurring water must be removed before most products made from wood can be used. The lumber dry kiln is the method most used by the forest products industry to remove the water and dry the lumber.

A lumber dry kiln is a building with a large chamber in which air is circulated by fans around the lumber it contains. The temperature and humidity of the air are automatically controlled and monitored, as the lumber is carefully dried.

Efficiency of the kiln is the total amount of energy entering versus that which actually does the work of removing the water. Operating techniques and design are important to the dry kiln efficiency. The energy that does not remove water is used to heat the wood, water, kiln structure, or is vented away and replaced. Reductions can be made in this nonworking energy use.

Dry kilns are notoriously energy inefficient when compared to other types of forest products processing operations. Although dry kilns can be as great as 72-percent efficient, most often they are in the 40- to 50-percent range with some as low as 23 percent (see table 1). Except for the introduction of prefabricated dry kilns, little work has been done to reduce dry kiln energy consumption since the 1950s. There are two very important reasons for this lack of improvement. First, until the mid-1970s

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the cost of energy was not as large a part of the total cost of drying as it is today. Second, replacement dry kilns are not often considered because twenty to fifty years is often the operational lifetime of a lumber dry kiln. These reasons often retarded new kiln research and design. However, rising energy costs and development of new kiln designs are providing impetus for improvement in kiln efficiency. The possibilities for improving dry kiln efficiency and for lowering manufacturing and consumer costs are great.

Lumber industry firms are very sensitive to price and cost changes. Small changes in unit production costs ($1 or $2 per MBF) can have sizable results when the transactions of large annual volumes of lumber (1 to 5 million BF) are considered. An estimated 500 million board feet of lumber were dried in the Tennessee Valley in 1980. A savings of as little as 1 dollar per MBF is worth 5 million dollars to the wood industry of the Tennessee Valley.

The cost of drying lumber is a large portion of the total cost of manufacturing lumber. Drying costs range between 50 to 150 dollars per MBF depending on the species, thickness and moisture content of the wood, and efficiency of the dry kiln. This variability is important to lumber firms which must control drying costs closely to remain competitive. A price difference of a few dollars per MBF can often mean the difference in a sale or purchase.

In table 1 energy use has been calculated based on the structures of the three major kiln types: prefabricated, block, and progressive. "Heat

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Table 1. Energy Use by Components for Kiln Types.

	Green yellow-poplar						Air-dried oak					
	Summer			Winter			Summer			Winter		
	Prfab.	Block	Progr.	Prfab.	Block	Progr.	Prfab.	Block	Progr.	Prfab.	Block	Progr.
	Percent of Total Btus Used											
To heat the kiln	6	6	5	7	7	6	6	5	4	7	6	5
To remove the water	77	75	68	72	69	62	40	35	28	38	33	23
Venting losses	12	12	11	15	14	13	36	33	25	31	26	19
Building losses	5	8	16	6	10	19	18	27	43	24	35	53
Total	100	100	100	100	100	100	100	100	100	100	100	100
	MBTU/MBF											
	3.8	4.0	4.3	4.1	4.3	4.8	2.7	3.0	3.9	2.8	3.3	4.6

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kiln" is the amount of energy needed to heat the dry kiln structure and the wood it contains to operating temperature. "Remove water" is the energy needed to extract water from the wood, the purpose of the kiln. "Vent loss" is the energy expelled from the kiln with moisture-laden air. "Building loss" is the energy lost through the walls, roof, doors, and floor of the structure.

Insulation has been used in the past as the primary method of reducing dry kiln energy consumption by slowing down heat losses of the large kiln building. However, except for the prefabricated-type dry kiln, insulation has not been a completely satisfactory method of reducing heat loss. Installation and protection of the insulation from moisture and mechanical damage have been principal difficulties. Also, it is very difficult to retrofit existing kilns, especially the older ones which have the highest heat losses.

Retrofitted insulation has a long-cost recovery period, often 10 to 20 years. This is a longer time period than most firms like. As insulation is added to kiln walls, its benefits diminish. This allows insulation to economically recover only a fraction of the total drying energy used. There is currently little potential for more than a 5- to 10-percent energy reduction for dry kilns using insulation.

Venting has not previously been seriously considered for reducing kiln energy consumption and costs. In almost all commercial dry kilns, moisture-laden air expelled from the kiln contains large concentrations of heat. Table 1 also indicates that 12 to 36 percent of the total energy consumed by a dry kiln is lost through the vents. In no other part in the lumber drying system is there such a high concentration of wasted energy. The vented hot air is a good heat transfer medium, so recovering energy from the vented air is where we looked for new alternatives to save energy and costs.

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PRELIMINARY WORK

During the process of drying, lumber gives off large amounts of water vapor into the surrounding kiln chamber. All types of conventional lumber dry kilns remove the moisture-laden air, and the temperature and humidity of the chamber air are controlled by the kiln operator. To maintain these conditions and encourage the fastest possible drying without damaging the lumber, the saturated air is vented and replaced with drier, outside air. The new air has the ambient temperature and humidity and must be heated and humidified. All of the heat in the expelled air is lost from the dry kiln and must be replaced by the heating system to maintain the kiln temperatures. The venting system of most dry kilns is run by compressed air controlled by pneumatic diaphrams. This provides a simple and reliable venting system which has been used successfully for many years with few changes.

The most promising method for recovering heat energy from vented air is a heat exchanger that takes the heat from expelled air and returns it to the kiln via the incoming air. This idea was first studied in detail and experimented with in the 1950s by Robert J. Hoyle (Hoyle, 1957) at Syracuse University. Hoyle used heat exchangers adapted to the now obsolete progressive kiln designs*. His research was 25 years ahead of its time, for only recently have major dry kiln manufacturing firms shown an interest in heat exchangers. Unfortunately, the economy forced the firms to delay most of their research and development work. However, Rosen and Chen (1979) showed that it was physically and economically feasible to install heat exchangers on veneer dryers.

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*Long chamber track kiln with a loading end and unloading end. As a stack of lumber is removed from one end, another is added to the other so the lumber moves (progresses) through different zones of temperature and humidity.

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In the summer of 1981 the dry kiln heat exchanger problem was approached in a new perspective by the Forest Industry Development staff at Tennessee Valley Authority (TVA). If existing "off the shelf" equipment could be used, it would greatly reduce the time needed from the drawing board to the finished product. If these units were modular and adaptable to existing kiln controls, the cost and maintenance would be reduced also. While this study was underway, Pfaff (1983) completed a study of a heat-pipe exchanger with a small, experimental kiln in Canada for a private firm. All study results pointed to the benefits of heat exchangers.

Preliminary Study

A preliminary study in 1981-1982 was conducted by TVA (Toennisson, 1981) at a commercial operation on an 80 MBF-capacity dry kiln. The study was designed to determine the amount and temperature of the vented air and the frequency of vent use. The results showed that the largest portion of vent usage took place during the first half of the kiln drying period and at temperatures below 160°F (see table 2).

The preliminary study also showed that any heat exchanger used for recovering energy from the vented air of a lumber dry kiln must be efficient at low temperature ranges, 100°-160°. Also, the heat exchanger must be able to withstand high humidities and work at varying temperatures called for in the drying schedule changes. The exchanger should be modular for easy installation and have access panels for cleaning and examination to prevent corrosion. A search for existing units was conducted to find an acceptable design.

The investment analysis for a hypothetical heat exchanger proved to be attractive. The estimate for an exchanger sized for an 80 MBF-capacity

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Table 2. Dry Kiln Venting Frequency.

Data gathered 1981 from 80 MBF direct-fired kiln at Charisma Chair.

Species thickness	Step number	Set Points Dry	Set Points Wet	Step time minutes	Vent time minutes	Vent time percent
4/4 Oak	1	120	95	3,140	2,734	28
	2	130	90	1,020	1,020	10
	3	140	96	1,440	1,440	15
	4	160	110	480	8	*
	5	180	130	3,000	50	1
	6	180	152	720	12	*
	Total					54
6/4 Poplar	1	150	122	110	9	4
	2	150	119	1,320	273	14
	3	160	110	2,320	928	1
	4	170	120	1,440	26	*
	5	180	128	600	13	*
	6	188	162	840	12	19
	Total					
5/4 Mixed	1	110	80	1,650	1,515	21
	2	130	100	1,140	286	4
	3	140	100	1,530	308	4
	4	155	106	1,410	228	3
	5	165	110	1,230	32	*
	6	175	120	108	1	*
	Total					32

*Less than 1 percent.

dry kiln was $9,000 for equipment and $3,000 for installation. Assuming a cost of $4.50 per thousand cubic feet of natural gas, the payout period before taxes is almost 1 year.

STUDY SCOPE AND OBJECTIVES

The data from the preliminary study suggested that a flat-plate heat exchanger would have to vent 6 to 7 thousand cubic feet of air per

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minute to maintain the existing venting and drying rates. These conditions yield a pressure drop of .50 to .75 inches of mercury. Two possible applications became apparent: The heat exchanger could be used with installed fans in an induced air method or used with existing circulating fans in a passive method. The passive method has many advantages and would not require extra fans, but there was not a unit on the market which could handle the air flow or the static pressure specified.

The heat exchanger chosen for the dry kiln application was an air-to-air, flat-plate type. It is a boxlike structure with incoming and outgoing air openings and contains a series of baffles where the hot exiting air exchanges heat via the plates to the cooler incoming air. The incoming and outgoing air have no direct physical contact; only heat is transmitted between airstreams. The primary attribute of a flat-plate exchanger is that it is simple to operate and easy to install without major kiln modifications. It is also the least costly and needs little maintenance.

To use the existing dry kiln equipment without major modifications and ensure the experiment would generate enough data for further studies, two centrifugal fans were added to the intake and exhaust. Both the intake and exhaust openings would be placed on one side of the circulating fans, allowing the exchanger fans to overcome any pressure difference when the circulating fans reversed direction.

A plan was developed to provide for the following objectives.

1. Move as quickly as possible, yet maintaining accuracy. The industry is in need of correct information.
2. Work closely with industry at all levels so that they fully understand applying the principles of heat exchangers to dry kilns.
3. Utilize equipment already in use by other industries to minimize cost and development time.

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4. By working with a commercial lumber drying firm testing results and evaluating alternatives, minimize the risk associated with implementing new technology.

5. Identify the good and bad points of a heat exchanger (efficiencies, operating temperatures, air volumes, performance, cost, and investment possibilities).

6. Monitor the unit and issue a final report.

7. Use the information to make recommendations for future installations.

STUDY PROCEDURE

A "Z - DUCT" Model 74* was chosen to be the study heat exchanger from several bidding manufacturers. Selection was not based on price or quality (all were close) but was the choice of Charisma Chair, Sweetwater, Tennessee, the cooperating dry kiln firm. The equipment was installed on an 80 MBF direct-fired dry kiln according to TVA's specifications: (1) the exchanger was placed on the roof of the kiln with the intake and exhaust openings on the same side of the circulating fan and (2) the existing controlling system was slightly modified to operate the two 5 hp fans. The setup used the pneumatic pulse of the kiln controller to trip a relay switch which started the fans. The release of the pulse turned the fans off after a 1-minute duration to eliminate possible motor damage of stopping and starting too quickly (see figures 1, 2, and 3, pages 26, 27, and 28).

It was not practical to secure data from every major lumber species, so yellow-poplar and red oak were selected as representative species. Yellow-poplar and red oak represent the low and the high, respectively, of the energy requirements of drying lumber in a kiln. Yellow-poplar uses 1.0 to 3.0 million

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*The use of model number or trade names is for reader association and identification only and implies no product endorsement by TVA.

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Btus/MBF and red oak 2.5 to 5.0 million Btus/MBF. Most of the energy needs for other species fall between these two. Therefore, a good picture of how different species affect heat exchanger use was obtained.

The following data were collected from each kiln charge.

1. Date and time started and completed.
2. Volume of lumber in each charge.
3. Species and thickness of lumber.
4. Moisture content of the charge at daily intervals.
5. Record of control settings for kiln temperatures.
6. Record of vent use.
7. Record of temperatures during venting cycles for:
    a. kiln wet bulb
    b. kiln dry bulb
    c. ambient air dry bulb
    d. ambient air wet bulb
    e. kiln to exchanger exhaust dry bulb
    f. exchanger exhaust dry bulb
    g. exchanger exhaust wet bulb
    h. exchanger intake dry bulb
    i. exchanger intake wet bulb
    j. exchanger to kiln dry bulb
8. Log of all incidents that occur during a kiln charge.

Equipment used during the study included a six-point temperature strip chart recorder. Probes were standard, electrical-resistance type located in strategic positions (see figure 2, page 27). Other equipment included a weather station, recording thermohygrometer, and an airflow meter.

During the venting cycle, the strip chart recorded the temperatures of the heat exchanger probes at 1.25-minute intervals. The resulting strip chart gives the temperature of these probes at the time of occurrence and therefore provides a permanent record of temperature changes by time. The data were gathered in a complete unit at the end of each kiln charge and taken to the TVA Forestry Building in Norris, Tennessee, where the data were

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transcribed, digitized on TVA's mainframe computer, and analyzed with FORTRAN and SAS programs.

The following equations, which were used in computing the heat value of the vented air, were derived from ASHRAE (1981) and modified to meet the studies' criteria. These equations were coded into the computer program used to calculate the amount of energy recovered from the exchanger.

Absolute Humidity:

Given: W = pounds of water/pounds of dry air

TWB = wet bulb °F

WS = water carrying capacity of air lbs/lbs dry air

1) $W = \{(1093 - 0.556 \times TWB) \times WS - 0.24 \times (TDB - TWB)\}/(1093. + 0.444 \times TDB - TWB)$

Air Volume:

Given: V = volume of dry air in cubic feet/pound of dry air

T = air temperature °F

2) $V = \{(359 \times (T + 460)/ 492\}/ 28.97$

Water Volume:

Given: WV = volume of water vapor in cubic feet

W = lbs water/lbs dry air from equation 1

V = volume of dry air in cubic feet from equation 2

3.1) $WV = + 0.012$

Then:

Water and air volume in cubic feet/lb dry air

3.2) $TV = WV + V$

Then:

lbs of air vented from kiln

3.3) PK = cubic feet of air vented / TV

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Heat of Air:

Given: BTU = Btus per pound of air

TDB = dry bulb F.

W = lbs water/lbs dry air

4.1) $BTU = 0.24 \times TDB + W \times (1061 + .444 \times TDB)$

Then:

4.2) Btus of air and water (BTUL) = PK × BTU

The recorded data were used to determine energy saved (Btus) by the heat exchanger. Absolute humidity was calculated using equation 1 for the air exhausting from the heat exchanger and the air going from the kiln to the heat exchanger. Air and water volume were calculated by equations 2 and 3.1, respectively, and then added together by equation 3.2 resulting in air and water vapor volume. Pounds of air with water vapor was determined with equation 3.3. Equation 4.1 was used to determine Btus in the air and water vapor. Finally, the energy saved by the heat exchanger was found by subtracting the Btu value of the air exhausted by the exchanger from the Btu value of the air going into the exchanger from the kiln.

COST OF HEAT EXCHANGER

The following costs of material and installation of the dry kiln heat exchanger are from invoices received by Charisma Chair. The category labeled "other items" consists of tubing, tape, fasteners, and such items.

Item	Cost
Heat exchanger	$ 5,367.71
Starters	378.43
Curb (support beam)	260.76
2 fans (5 hp)	2,297.28
Freight	235.33
Installation and other items	1,500.00
Total	$1,0048.51

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RESULTS

From April 1982 to April 1983 ten complete runs of lumber were dried and recorded using the heat exchanger installed at Charisma Chair. Eight of the charges studied were air dried, two were green (greater than 25 percent MC). They consisted of 4/4, 5/4, 6/4, 8/4, and 10/4 yellow-poplar; 4/4 and 5/4 red oak; and one run of 6/4 sweet gum. The average calculated efficiency of the heat exchanger for all study runs was 45.9 percent, with yellow-poplar averaging 47.1 percent (32.4 to 61.4 range) and red oak averaging 44.3 percent (22.8 to 66.2 range). The 10 runs averaged 36.3 million Btus saved per run, with yellow-poplar averaging 27.4 million Btus. The energy saved averaged on a thousand board foot basis were 452.0 MBtus/MBF for all the study charges, 311.7 MBTUs/MBF for yellow-poplar, and 656.0 MBTUs/MBF for red oak. Using $4.50 per thousand cubic feet of natural gas, the average energy savings for all charges is $1.95 per MBF, $1.40 per MBF for yellow-poplar, and $3.74 per MBF for red oak.

Venting performance of the heat exchanger was as predicted. Venting frequency was species dependent. Yellow-poplar's mean venting cycle time was 4 minutes, with most of the venting occurrences shorter than 10 minutes. Oak's mean venting cycle was 12 minutes, with most of the venting occurrences 60 minutes or less (figure 4, page 29).

The heat exchanger appeared to work more efficiently during the winter runs when more energy is saved per MBF (see table 4). The difference between the temperature outside the kiln to the operating temperatures inside the kiln is important. The larger the temperature difference, the more energy the exchanger has to work with and can save. Although this study did not systematically approach the question, it is apparent that kiln operating temperatures below 100°F would not be very efficient on days above 90°F.

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Table 3. Heat Exchanger Venting Efficiency.

Run number and species	Venting measured	Calculated venting	Percent of calculated
	---Thousand Cubic Feet of Air---		
2) Poplar	8,307	8,616	103
3) Gum	4,974	3,139	63
4) Oak	67,990	41,973	62
5) Poplar	5,078	5,532	100
6) Poplar	5,442	2,914	54
7) Poplar	6,189	6,171	100
8) Oak	23,750	9,800	41
9) Poplar	8,817	5,058	57
10) Oak	21,135	6,238	30
11) Poplar	4,909	4,633	94

Table 4. Venting Frequency, Duration, and Efficiency.

	Average of similar runs from air-dried material			
	Yellow-poplar		Red oak	
Venting frequency	227		519	
Venting duration	4.2 minutes		12.1 minutes	
Exchanger efficiency	47.2		44.6	
Delta 'T'*	Summer	Winter	Summer**	Winter
	35.0	51.1	19.4	39.8
Million Btus saved per MBF	263.9	407.0	973.1	758.7

*Ambient temperature--kiln operating temperature.
**Summer oak was a green charge.

Lumber species affect the amount of energy available and portions of energy saved by the heat exchanger. Red oak has more energy available

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Table 5a. Summary of Dry Kiln Heat Exchanger Test Charges.

Charge description	Charges # 2-6				
	10/4 poplar	6/4 gum	5/4 red oak	6/4 poplar	8/4 poplar
Volume MBF	108.6	81.6	73.9	83.6	99.0
Date started	5/27/82	6/01/81	6/15/82	7/20/82	9/07/82
Time in kiln hours	147.0	98.6	397.1	51.8	47.9
Times vented	230	124	857	167	206
Hours vented	16.5	9.5	130.0	9.7	10.3
Average vent time min.	4.3	4.6	9.1	3.5	3.0
Thousand cubic feet of air vented	830.7	4,973.6	67,347.7	5,077.8	5,442.4
Starting MC percent	20	17	42	15	15
Kiln dry bulb F	165.5	173.0	118.0	174.0	176.7
Kiln wet bulb F	126.8	136.2	99.0	130.4	137.2
Ambient Air F	64.2	71.3	75.4	78.0	70.2
Ambient humidity	60.3	71.1	81.8	86.8	65.2
Exchanger Air in F	141.6	133.1	11.2	164.0	137.0
Exchanger air out F	90.5	85.7	87.3	108.8	92.1
Million Btus saved	36,539.0	13,495.3	71,922.3	16,234.9	20,823.2
Thousand Btus/MBF	336.43	165.48	973.07	194.23	210.26
Value gas $4.50/ft^3	164.43	60.73	323.66	73.06	93.71
Value saved per MBF	1.51	0.74	4.38	0.87	0.95

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Table 5b. Summary of Dry Kiln Heat Exchanger Test Charges.

Charge description	Charges # 7-11				
	4/4 poplar	4/4 oak	6/4 poplar	4/4 red oak	4/4 poplar
Volume MBF	76.0	74.8	83.2	74.4	80.7
Date started	9/24/82	11/21/82	1/17/83	2/03/83	3/03/83
Time in kiln hours	140.6	135.9	102.3	171.4	92.7
Times vented	273	310	315	399	176
Hours vented	12.7	81.6	31.5	74.1	16.8
Average vent time min.	2.8	15.8	6.0	11.4	5.8
Thousand cubic feet of air vented	6,188.8	23,657.3	8,817.4	21,134.5	4,787.8
Starting MC percent	27	21	25	22	21
Kiln dry bulb F	148.6	143.0	170.0	150.0	179.0
Kiln wet bulb F	123.8	112.0	127.0	113.0	141.0
Ambient Air F	65.1	50.6	29.1	34.9	62.8
Ambient humidity	61.3	70.8	36.4	63.8	47.4
Exchanger Air in F	141.2	133.3	144.1	134.5	163.5
Exchanger air out F	99.7	79.2	71.1	55.1	92.5
Million Btus saved	23,935.0	50,776.9	41,444.6	62,383.5	25,566.9
Thousand Btus/MBF	314.8	678.4	498.0	839.0	316.7
Value gas $4.50/ft^3	107.71	228.49	186.50	280.29	115.05
Value saved per MBF	1.42	3.05	2.24	3.78	1.43

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over the drying cycle, but a smaller portion is recovered by the heat exchanger. This may be because of the low dry kiln operating temperatures and long step times needed to dry red oak. When drying red oak, the exchanger was able to save 14,000 Btus per MBF per minute of vent operation. Yellow-poplar is fast dried at high temperatures and does not vent as frequently or as long as red oak. This results in less energy available for the heat exchanger during the drying cycle. When drying yellow-poplar, however, the exchanger is able to recover more of the available energy and save about 30,000 Btus per minute (figure 6, page 31).

Factors predicting heat exchanger efficiency are suggested from the data. The efficiency is influenced primarily by chamber wet bulb temperature and the temperature difference between ambient and inside the kiln chamber (see figure 5, page 30). The greater the wet bulb, the greater the heat exchanger efficiency because the moister air has more heat value by weight (Btus) to give up.

During the 10 runs, the dry kiln consumed 2005.5 million Btus from which the heat exchanger saved 364.1 million Btus or 18.2 percent of the total. Yellow-poplar runs showed a total savings of 18.9 percent and red oak 14.4 percent.

Table 6. Percent of Total Energy Saved per Kiln Charge.

Kiln charge	Total Btus used*	Btus saved		Percent Btus saved
	---------Million Btus---------			
2) Poplar	157.9	36.5		23.1
3) Gum	92.3	13.5		14.6
4) Oak	477.3	72.7		15.2
5) Poplar	91.4	16.2		17.8
6) Poplar	101.8	20.8		20.5
7) Poplar	140.2	23.9		17.1
8) Oak	346.3	50.9		14.7
9) Poplar	156.2	41.4		26.5
10) Oak	218.4	62.4		28.6
11) Poplar	223.7	26.1		11.8
Total	2,005.5	364.1	Average	18.2

*Estimated from TVA's Dry Kiln Energy Program (6).

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STUDY MODIFICATIONS AND IMPORTANT OBSERVATIONS

The following events occurred during the testing of the heat exchanger. They are considered to have had significant effect on the study and/or exchanger performance. The cause, effect, and corrections, if any, are described.

Louvers were added to the heat exchanger shortly after the first test run in April 1982. They were installed to stop the backflow of air through the heat exchanger while the venting fans were off. They were designed to be opened by incoming or outgoing air pressure when the venting fans were in operation.

A timer was installed at the beginning of the project to prevent possible damage to the venting fan motors by too frequent venting occurrences. Two minutes was the original time setting. This was changed to 1 minute when the danger of frequent venting and the time interval for fan slowdown was found to be smaller than expected.

Condensation collection on the exhaust side of the heat exchanger was found to be greater than expected. At times there was almost a constant flow from the drain. However, the installed drain system was able to remove the water at the rate it was condensed.

After the first run of oak, corrosion became noticeable around the intake and exhaust openings. On inspection of the interior, corrosion was found on all exposed metal. Every place the original protective coating was broken, there was corrosion; for example on screws, doors, fittings. The rust was cleaned and a thick coating of black enamel applied to the exchanger, inside and out. At the end of the testing period, corrosion was found to have reoccurred. This could significantly shorten the length of service of the heat exchanger.

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The original fan and exchanger setup allowed venting of at least 6,000 cubic feet of air per minute. This estimate was based on the assumed calculated venting needs. After several months of testing, a variable-speed pulley assembly was placed on each of the fans. By reducing the airflow to 3,000 cubic feet per minute, the exchanger was found to be operating at a much greater efficiency and venting for longer periods. Slowing airflow allows the air more time near the exchanging baffles, thus giving more time for energy transfer.

CASHFLOW ANALYSIS

By expanding the test data to annual volume expected for an 80 MBF-capacity kiln, it is possible to do some financial analyses of the exchanger performance. Below is a cashflow sheet for the operation at Charisma Chair which dries about 2,500 MBF per year of oak, gum, and yellow-popiar. All cashflows were computed with the computer program designed by George Harpole (1977).

Using the same base data in table 7, the cashflows for the maximum capacity annual production were computed for the mixed charges. This analysis was repeated for both red oak and yellow-poplar to project annual estimates for each species.

Using the same base data in table 7, the cashflows for the maximum capacity annual production were computed for the mixed charges, red oak, and yellow-poplar.

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Table 7. Cashflow Analysis - 6,000 CFM with 5 Hp Fans.

Heat exchanger cost and installation	10,048.00
Investment tax credit, 10 percent	1,004.80
Energy tax credit, 10 percent	1,004.80
Saved per MBF - mixed $1.90, yellow-poplar $1.40 oak $3.74 (5 percent annual inflation rate included)	
Operating cost - electricity $.05 kilowatt hour (10-percent yearly increases included)	
Maintenance - $100 every two years (paint)	
Borrowing rate, 12 percent; reinvestment rate, 9 percent	
Tax rate, 45 percent	

Table 8. Cashflow for Charisma Chair Heat Exchanger.

	Existing operation						
Unit	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
MBF lumber, dried	2,500	2,500	2,500	2,500	2,500	2,500	2,500
Savings per MBF	$2.45	$2.57	$2.70	$2.84	$2.98	$3.13	$3.28
Gross savings	6,125	6,425	6,750	7,100	7,450	7,825	8,200
Interest income	0	659	1,093	1,519	1,959	2,426	2,928
Gross revenues	6,125	7,084	7,843	8,619	9,409	10,251	11,128
Electric cost	140	155	170	187	205	225	247
Cost per MBF	.06	.06	.07	.07	.08	.09	.10
Depreciation	4,500	2,250	1,125	563	281	141	140
After tax profit	2,826	2,574	3,602	4,328	4,908	5,437	5,907
After tax earnings	7,326	4,824	4,727	4,891	5,189	5,578	6,047
Accumulated cashflow	-2,722	2,102	6,829	11,720	16,909	22,487	28,534

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Table 9. Cashflow for Charisma Chair Heat Exchanger.

Unit	Drying only red oak 30 cycles, 12 days Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
MBF lumber, dried	2,200	2,200	2,200	2,200	2,200	2,200	2,200
Savings per MBF	$4.70	$4.93	$5.18	$5.45	$5.72	$6.00	$6.29
Gross savings	10,340	10,846	11,395	11,986	12,577	13,210	13,843
Interest income	0	869	1,533	2,211	2,929	3,699	4,531
Gross revenues	10,340	11,715	12,928	14,197	15,505	16,908	18,374
Electric cost	140	155	170	187	205	225	247
Cost per MBF	.06	.06	.07	.07	.08	.09	.10
Depreciation	4,500	2,250	1,125	563	281	141	140
After tax profit	5,153	5,131	6,409	7,408	8,274	9,113	9,909
After tax earnings	9,653	7,381	7,534	7,971	8,555	9,254	10,049
Accumulated cashflow	-395	7,776	15,310	23,281	31,836	41,090	51,139

Table 10. Cashflow for Charisma Chair Heat Exchanger.

Unit	Drying only yellow-poplar 60 cycles, 6 days Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
MBF lumber, dried	5,310	5,310	5,310	5,310	5,310	5,310	5,310
Savings per MBF	$1.76	$1.85	$1.94	$2.04	$2.14	$2.25	$2.36
Gross savings	9,346	9,803	10,299	10,833	11,367	11,939	12,512
Interest income	0	811	1,411	2,019	2,658	3,342	4,080
Gross revenues	9,346	10,614	11,710	12,852	14,025	15,281	16,592
Electric cost	140	155	170	187	205	225	247
Cost per MBF	.06	.06	.07	.07	.08	.09	.10
Depreciation	4,500	2,250	1,125	563	281	141	140
After tax profit	4,511	4,419	5,625	6,540	7,320	8,064	8,759
After tax earnings	9,011	6,669	6,748	7,103	7,601	8,205	8,899
Accumulated cashflow	-1,037	5,632	12,380	19,483	27,084	35,289	44,188

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Table 11. Cashflow for Charisma Chair Heat Exchanger.

Unit	Drying mixed @ capacity 52 cycles, 7 days Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
MBF lumber, dried	2,300	4,300	4,300	4,300	4,300	4,300	4,300
Savings per MBF	$2.45	$2.57	$2.70	$2.84	$2.98	$3.13	$3.28
Gross savings	10,535	11,051	11,610	12,212	12,814	13,459	14,104
Interest income	0	873	1,541	2,223	2,944	3,718	4,555
Gross revenues	10,535	11,924	13,151	14,435	15,758	17,177	18,659
Electric cost	140	155	170	187	205	225	247
Cost per MBF	.06	.06	.07	.07	.08	.09	.10
Depreciation	4,500	2,250	1,125	563	281	141	140
After tax profit	5,196	5,274	6,453	7,452	8,318	9,157	9,951
After tax earnings	9,696	7,424	7,578	8,015	8,599	9,298	10,091
Accumulated cashflow	-352	7,072	14,650	22,665	31,264	40,562	50,653

Table 12. Summary of Cashflows for Heat Exchanger Savings for 80 MBF Direct-Fired Natural Gas Kiln at $5.65 per MCF.

	Savings per MBF	MBF dried per year	Composite ROR	Breakeven savings	Payback time yr	Accumulated savings 7y
Charisma actual production	$2.45	2,500	21.7	$.80	1.56	29,600
Mixed capacity	$2.45	4,300	29.7	$.49	1.05	51,700
Red oak capacity	$4.70	2,200	29.5	$.90	1.05	51,400
Yellow-poplar capacity	$1.76	5,300	27.6	$.41	1.15	45,200

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There is a difference in the savings per MBF between red oak and yellow-poplar. This is offset, however, by the difference in their drying times, resulting in very similar cashflows for both species. Also the mixed capacity production results showed that drying 25 percent oak did not greatly affect the financial picture. It appears that differential savings of the species will not significantly affect the total annual savings when the kiln is used to capacity.

The return on investment for this example (an 80 MBF, direct-fired, natural gas kiln) is well within the limits predicted by the feasibility study. The heat exchanger will pay for itself in about 1 year and over a 7-year period save about $50,000 worth of natural gas.

RECOMMENDATIONS

The original concept of using a ready made heat exchanger was not changed during the study. Certain modifications to the original design were necessary to produce the best efficiency and expedite installation. Listed below are recommendations determined from events of the study.

1. Off-the-shelf equipment can be used for all equipment needs.
2. The exchanger should be sized carefully to obtain the best results. A 3,000 CFM unit with 1 to 2 hp fans is the best combination for an 80 MBF dry kiln.
3. Control of the heat exchanger should be through the existing dry kiln controller by using a pneumatic switch, timer, and fan starter assembly.
4. Louvers are needed to prevent air from escaping when the venting fans are off. They should open with air pressure and close by gravity.
5. All aluminum construction is needed to prevent corrosion.
6. Modular heat exchanger units constructed in increments of air volume capacity would have great value in quickly and simply converting the many shapes and sizes of existing dry kilns.

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FUTURE WORK

Study results indicate that the relationship between kiln size and heat exchanger air volume is linear for package-type dry kilns. Most of the track type and old progressive kilns have a greater chamber air volume to lumber capacity ratio, which could influence the amount of air available to the heat exchanger. Future work is needed to determine if a different set of specifications will be needed for track and progressive-type kilns.

The passive system, which was discarded because of equipment difficulties early in the study, has been reconsidered. New equipment, which has recently come on the market, has some of the important specifications that a passive system needs in order to be effective. These new units of 1,000 CFM capacity are the size which can fit over the existing vent openings. The baffles can be preset at the factory to overcome internal pressure. The units can be installed in series if needed to meet air capacities of different sized dry kilns. This study indicates that a passive heat exchanger should be looked at carefully again. Charisma Chair has ordered a passive unit to test on their second dry kiln.

It was noted that when the air speed across the exchanger baffles was reduced, efficiency increased. There is no doubt that an air speed is most efficient, slow enough to allow good heat transfer, and still fast enough not to affect lumber drying. More work is needed to find this optimum speed and its effect on the kiln.

CONCLUSION

A demonstration/experiment of the heat exchanger equipment in actual operation on a dry kiln was conducted with a private lumber drying firm, Charisma Chair, Sweetwater, Tennessee.

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The exchanger is simple and easy to install. It requires no major modifications to the kiln and can be intergrated into the existing control system. There is no change in the operation of the kiln, and the operator can use normal procedures. This exchanger was placed on the roof, but it could be installed in any location that is convenient to the user as long as the intake and exhaust openings are on the side of the fans.

The investment is relatively small; 10 thousand dollars is less than 7 percent of the cost of a new 80 MBF capacity dry kiln. Analysis indicates the system will pay for itself in 1 year regardless of the species dried. Any species-related difference in heat exchanger performance is equalized when the annual maximum capacity is dried.

The savings of $1.40 (poplar) to $3.74 (oak) per MBF for the 80 MBF capacity direct-fired, gas-fueled kiln is a significant reduction in the cost of drying. Using a 75 dollar drying cost, poplar has a 2-percent savings and oak 5 percent. This cost savings can help a firm be more competitive.

The 18-percent reduction is important for almost all dry kiln operations. For kilns using fossil fuel, it saves money, energy, and makes them less dependent on increasingly expensive fossil fuels. For wood waste-using plants, it would be possible to add new kilns without new boiler capacity, reduce or eliminate the need to buy extra fuel for winter, and reduce wood waste storage space.

This application of an off-the-shelf, flat-plat heat exchanger to a lumber dry kiln shows considerable promise. This equipment does have some problems with corrosion, but overall it has performed very well with a minimum of effort and maintenance. With the recommendations for changes and suggestions for future operations, it should be possible to install heat exchangers on any commercial dry kiln using generic equipment already being mass produced and readily available.

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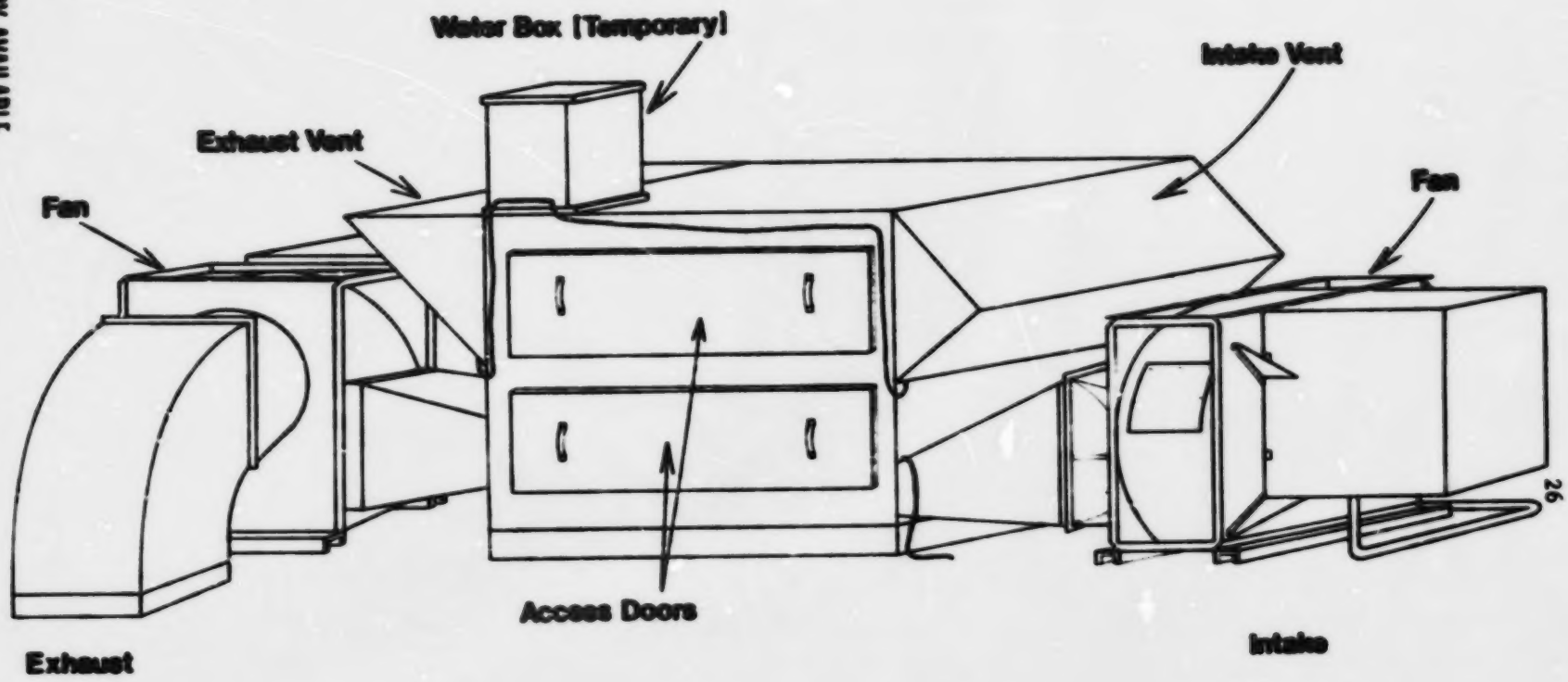
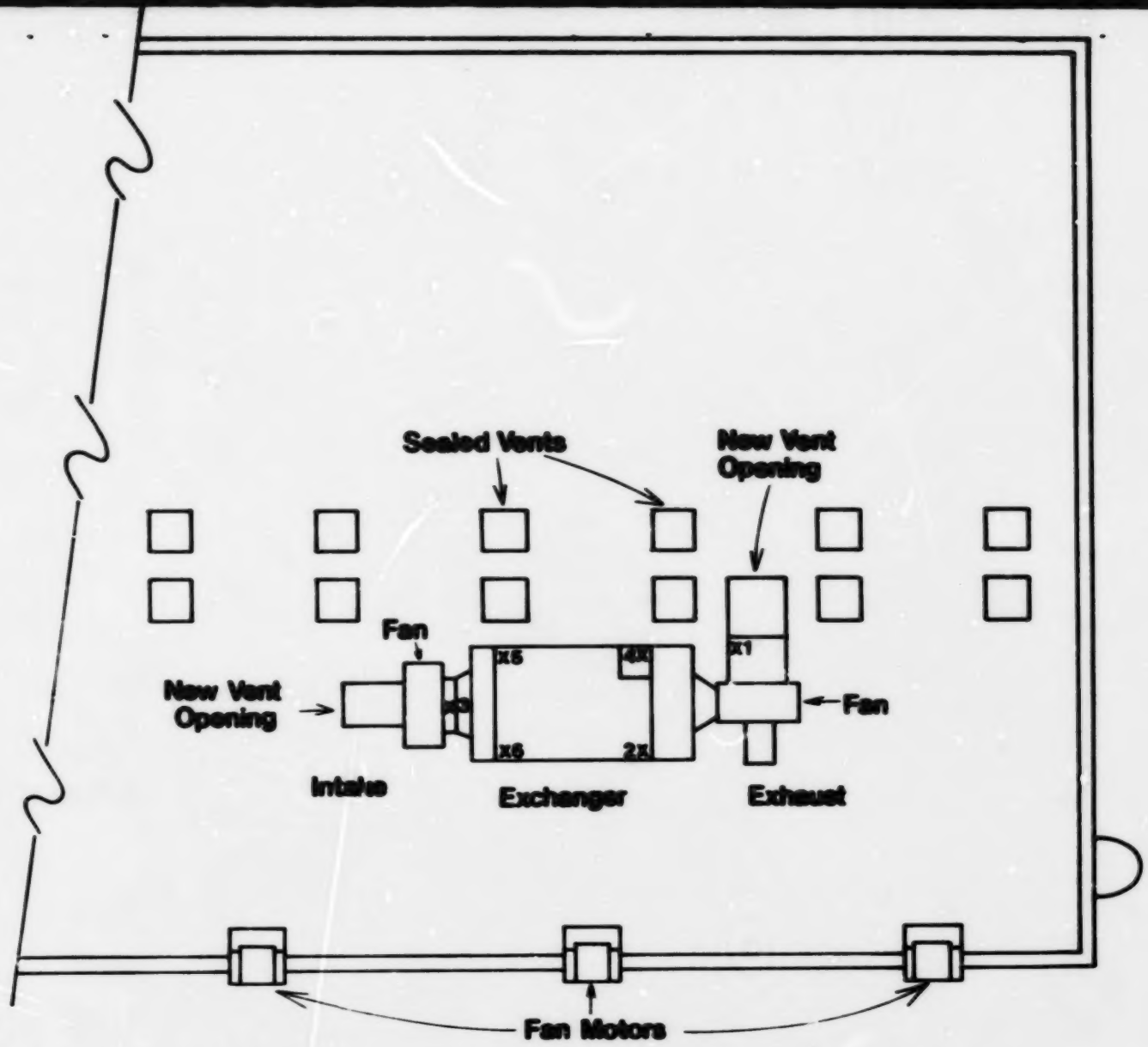


LUMBER DRY KILN HEAT EXCHANGER

6,000 CFM 5HP FANS

Figure 1



KILN ROOF WITH HEAT EXCHANGER (OVERHEAD VIEW)
Probe Locations Marked (x)
Figure 2

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Figure 3

CONTROL MODIFICATIONS FOR HEAT EXCHANGER

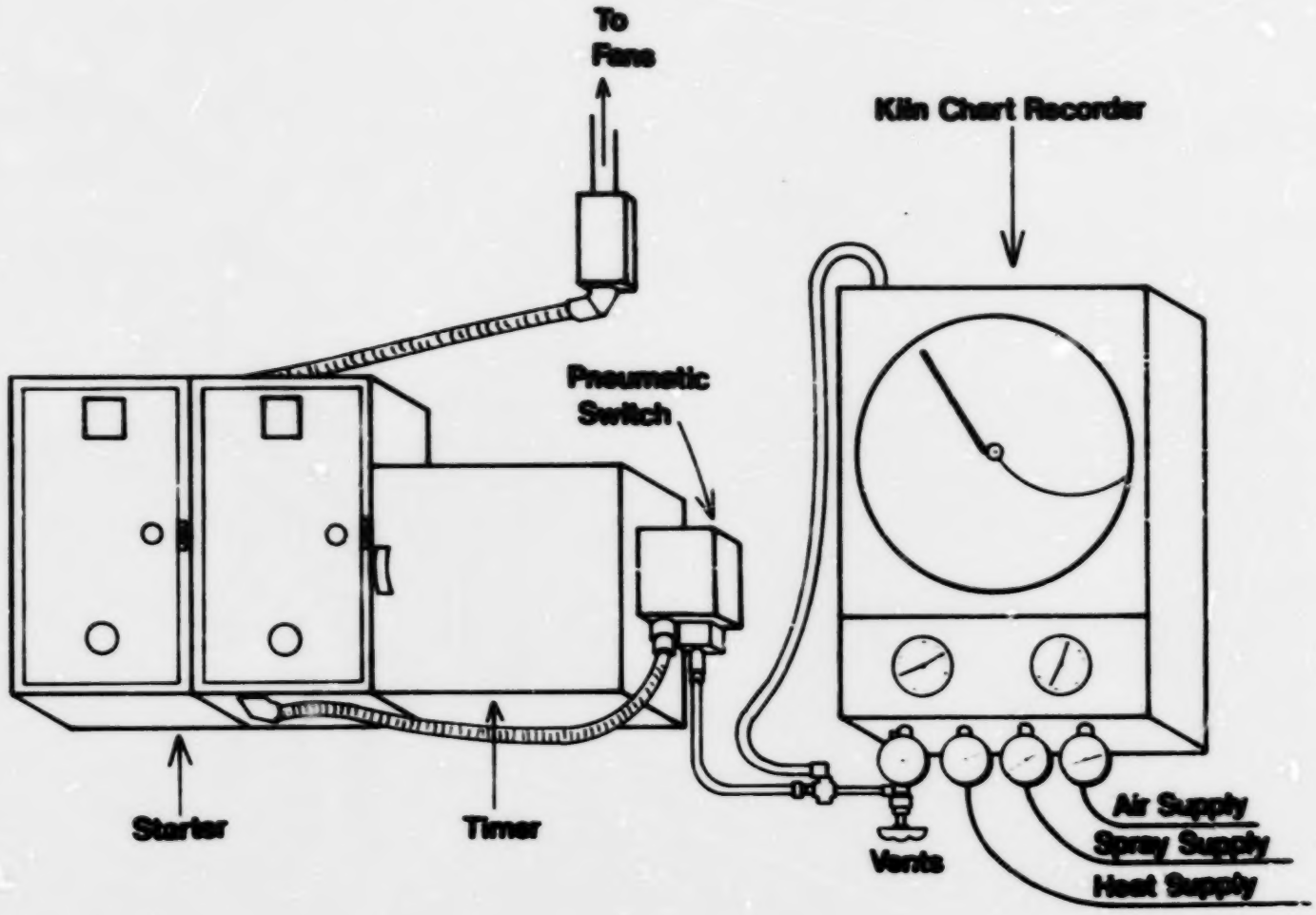

Figure 4. Heat Exchanger Venting Frequency.

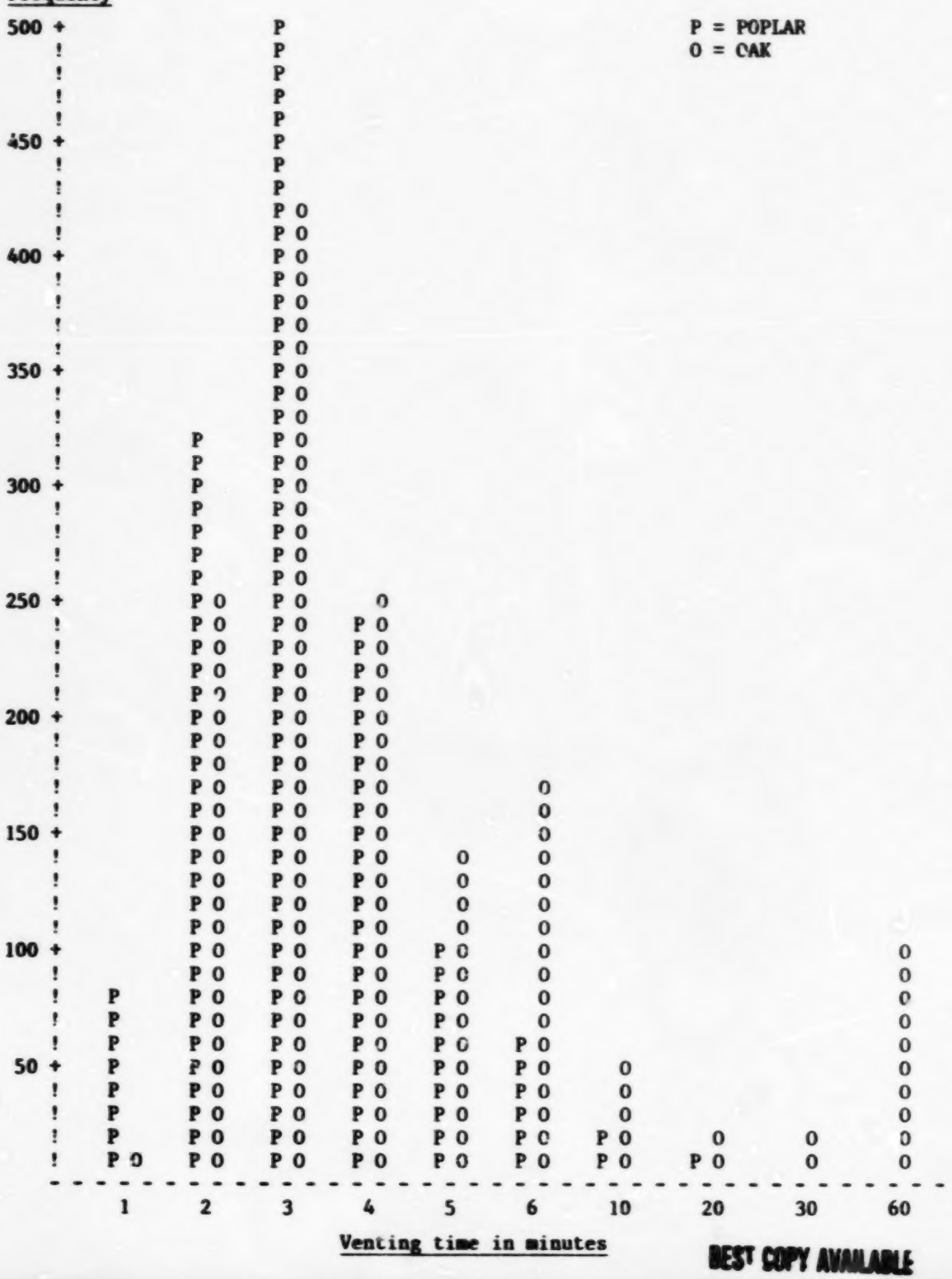

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Figure 5. Plot of Chamber Wet Bulb and Btus Lost by Kiln Per Minute.

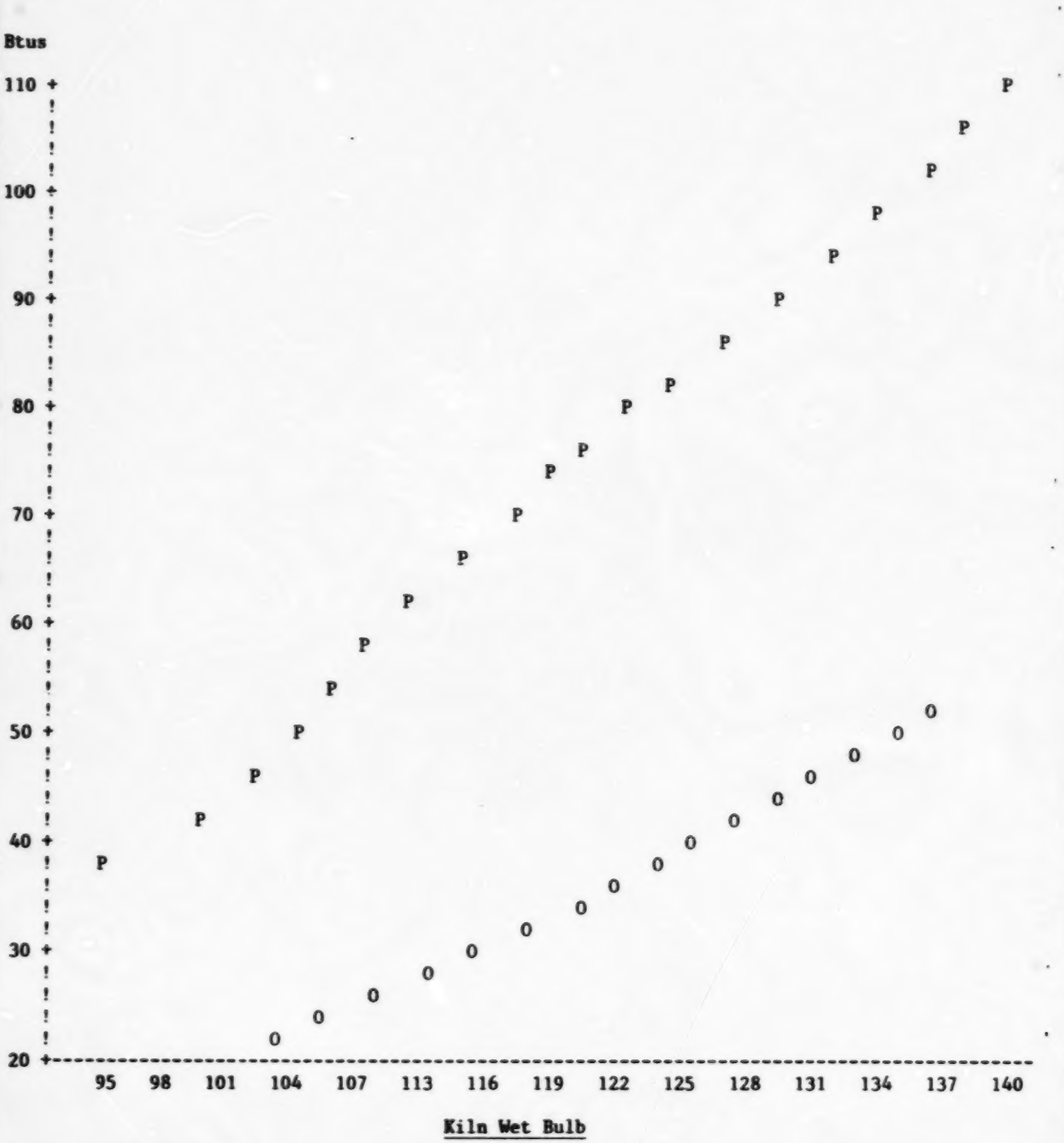

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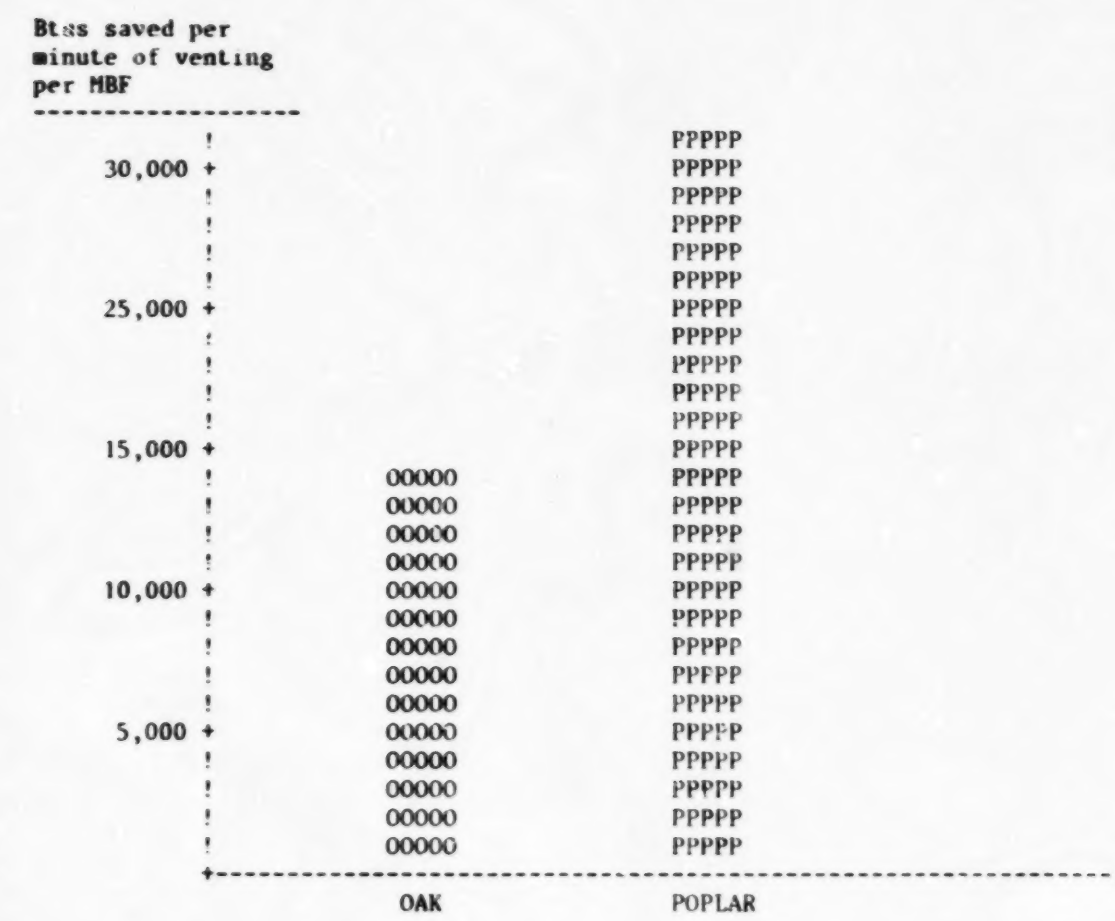
Figure 6. Btus Saved per Minute.



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REFERENCES

ASHRAE. 1981. American Society of Heating, Refrigerating, and Air Conditioning Engineers. Chapter 4.

Barr, Anthony J., James H. Goodnight, John P. Sall, and Jane T. Helwig. 1976. A Users Guide to SAS. SAS Institute, Inc.

Corder, Stanley E. 1980. Potential for Energy Recovery from Lumber Dry Kilns. Forest Products Journal. August.

Harpole, George. 1977. Cashflow Analysis Program. USDA.

Hoyle, Robert J. 1957. Heat Economy in Lumber Drying. Syracuse University. Master Thesis.

Kent, Albert C., Howard Rosen, and David A. Crotty. 1979. Energy Conservation in Wood Dryers Using Regenerative Heat Exchange. Carbondale, Illinois. USDA.

Murrill, Paul W. and Cecil L. Smith. An Introduction to Fortan IV. Thomas V. Crowell Co., Inc.

Pfaff, F. 1983. Application of an Air-to-Air Heat Exchanger for Recovery of Exhaust Heat from Dry-Kiln Ventilators. Forintec Canada Corp.

Rasmussen, Edmund F. 1961. Dry Kiln Operators Manual. Agriculture Handbook No. 188, USDA.

Toennisson, R. L. 1979. Dry Kiln Energy Use. Tennessee Valley Authority, Norris, Tennessee. Unpublished.

Toennisson, R. L. 1981. Heat Exchanger Feasibility. Tennessee Valley Authority. Unpublished.

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